A Model of Canopy Photosynthesis Incorporating Protein Distribution Through the Canopy and its Acclimation to Light, Temperature and CO_2

The distribution of photosynthetic enzymes, or nitrogen, through the canopy affects canopy photosynthesis, as well as plant quality and nitrogen demand. Most canopy photosynthesis models assume an exponential distribution of nitrogen, or protein, through the canopy, although this is rarely consistent with experimental observation. Previous optimization schemes to derive the nitrogen distribution through the canopy generally focus on the distribution of a fixed amount of total nitrogen, which fails to account for the variation in both the actual quantity of nitrogen in response to environmental conditions and the interaction of photosynthesis and respiration at similar levels of complexity.

This study presents a model of canopy photosynthesis for C_3 and C_4 canopies that considers a balanced approach between photosynthesis and respiration as well as plant carbon partitioning. Protein distribution is related to irradiance in the canopy by a flexible equation for which the exponential distribution is a special case. The model is designed to be simple to parameterize for crop, pasture and ecosystem studies. The amount and distribution of protein that maximizes canopy net photosynthesis is calculated.

The optimum protein distribution is not exponential, but is quite linear near the top of the canopy, which is consistent with experimental observations (Figure 1 and Figure 2). The overall concentration within the canopy is dependent on environmental conditions, including the distribution of direct and diffuse components of irradiance.

The widely used exponential distribution of nitrogen or protein through the canopy is generally inappropriate. The model derives the optimum distribution with characteristics that are consistent with observation, so overcoming limitations of using the exponential distribution. Although canopies may not always operate at an optimum, optimization analysis provides valuable insight into plant acclimation to environmental conditions. Protein distribution has implications for the prediction of carbon assimilation, plant quality and nitrogen demand.

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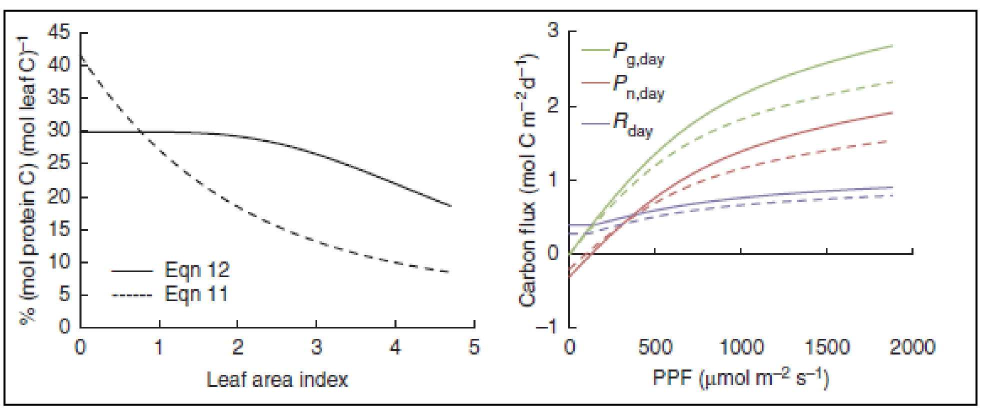

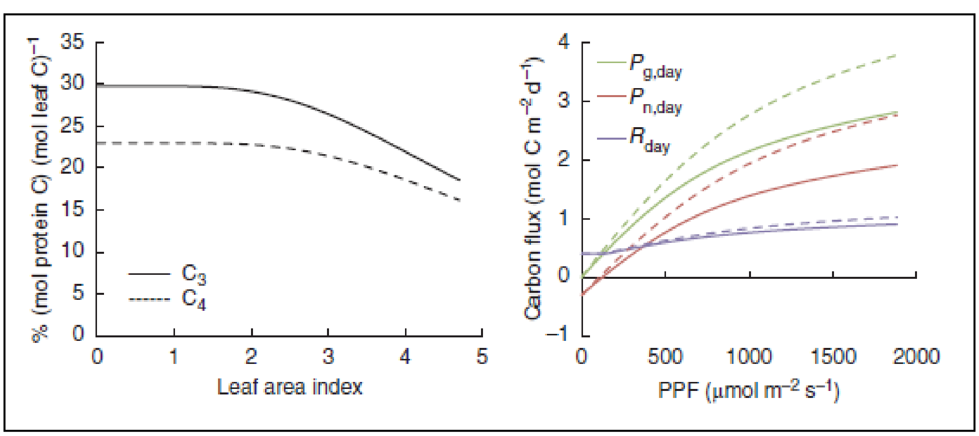

Figure 1 (left, top). The graph on the left shows the protein concentration distribution through the canopy [% mol protein C (mol total leaf C)$^{-1}$, as a function of leaf area index, optimizing daily net photosynthesis. The solid line corresponds to protein distribution through the canopy described by Eqn. 12 (see full paper), which describes protein decline through the canopy in terms of irradiance within the canopy relative to that at the top. The broken line represents the exponential distribution, corresponding to Eqn. 11 (see full paper), which optimizes the prescribed amount of nitrogen in order to maximize canopy gross photosynthesis. The graph on the right is the corresponding daily rates of gross photosynthesis ($P_{g,day}$), net photosynthesis ($P_{n,\,day}$) and respiration (R_{day}) vs. instantaneous photosynthetic photon flux (PPF) density, I_0.

Figure 2 (left, bottom). As for Figure 1, but the solid and broken lines are for C_3 and C_4 canopy, respectively.

Johnson, I., J.H.M. Thornley, J.M. Frantz, and B. Bugbee. 2010. Modelling photosynthetic enzyme level and distribution through canopies in relation to canopy photosynthesis and its acclimation to light, temperature and CO_2. Annals of Botany. 106:735-749.